Title of Investigation:

Superfluid Gyroscope for Pointing Future High-Resolution Telescopes

Principal Investigator:

Dr. Keith Gendreau (Code 662)

Other In-house Members of Team:

Dr. Zaven Arzoumanian (Code 662) and Dr. Fred Finkbeiner (Code 662)

External Collaborators:

Dr. Keith Schwab (University of Maryland-College Park)

Initiation Year:

FY 2004

Aggregate Amount of Funding Authorized in FY 2003 and Earlier Years:

$0

FY 2004 Authorized Funding:

$107,000

Actual or Expected Expenditure of FY 2004 Funding:

Contracts: $32,000 to Precision Crygenic Systems; $28,000 to Chase Research Crygenics; $5,000 to Quinstar Technologies.
Grants: $20,000 to Dr. Fred Finkbeiner and $20,000 to Dr. Zaven Arzoumanian

Status of Investigation at End of FY 2004:

To be continued in FY 2005 with funds remaining from FY 2004 and earlier years

Expected Completion Date:

December 2005

Purpose of Investigation:

Future high-resolution telescopes will need revolutionary technologies to lock onto targets. Galileo could get by using his eyes, a steady hand, and a simple stand to point his 10-arcsecond-resolution telescope at Jupiter and see the Jovian moons. Today, the Hubble Space Telescope (HST), which is about a 0.1-arcsecond-resolution telescope, uses a $450 million, closet-sized interferometric Fine Guidance Sensor (FGS) to point to within 10 milliarcseconds at distant galaxies. In the next few decades, NASA is considering several missions that will have angular resolutions greatly surpassing that of HST. The most ambitious will be the MicroArcsecond X-ray Imaging Mission (MAXIM), which will have sub-microarcsecond imaging capability to resolve the surface or event horizon of a black hole. The proposed Stellar Interferometer (SI) mission requires 100-microarcsecond-resolution imaging to study the solar cycles of nearby stars in the ultraviolet band. These missions and others will have an extremely challenging pointing problem, which likely will require non-celestial references. Here, we propose a gyroscope reference, with enough angular stability to satisfy the requirements of future sub-milliarcsecond telescopes. We propose to build a gyroscope that exceeds the performance of the best existing gyros—those used in the Gravity Probe B mission—by using superfluids. Objectives include providing NASA with:

- A novel technology for determining rotation. This will be an extremely stable reference for sub-milliarcsecond telescopes.
- An instrument that will be extremely sensitive to the Earth's rotation. This gyroscope will be sensitive to subtle changes in Earth rotation due to tides and atmospheric changes.

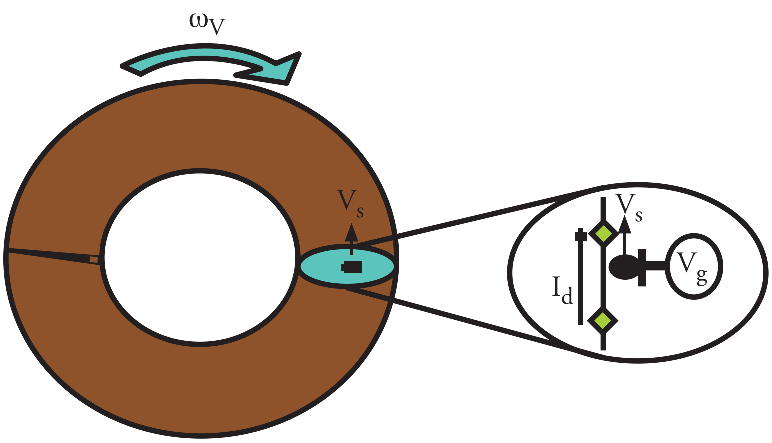

Figure 1. The superfluid gyro consists of a closed path (the large torus to the left) that rotates with an angular velocity ω_v. Within the path is a superfluid that flows in such a way as to negate any change in net vorticity. A membrane with a defined aperture (exploded to the right) restricts the flow so that a superfluid flow (V_s) passes through the aperture. Across this aperture, we assemble an SET circuit. We will measure the change in angular velocity of the gyroscope by sensing the change of the drain to source current (I_{ds}) modulated by the changing dielectric constant between the gate and the drain-source due to the density change of the superfluid. This density change is driven by the change in V_s, which is in turn driven by ω_v.

FY 2004 Accomplishments:

Funding for this effort began in March 2004. Before funding became available, we specified and sought quotes for some of the specialized cryogenic equipment we would need. Within 1 week of receiving funding, we submitted purchase requests along with quotes and sole source justifications. This was done as early as possible because it takes 3 to 4 months to receive these items once they are ordered. The Goddard Space Flight Center procurement process was particularly sluggish this year and it was not until July 2004 that these items were actually ordered. As of early December 2004, we still had not received the cryogenic equipment we needed.

To successfully operate a superfluid gyroscope, a cooling platform has to fulfill the following requirements:

- Very low-vibration environment
- Operational Temperature (OT) of about 0.3K at 10μWatt
- OT hold time of 72 hours (guaranteed) or more, and
- Platform can be tilted during operation.

Furthermore, a cooling platform should allow:

- Easy access to the experimental setup (i.e. gyroscope, cold electronics)
- Establishing a low-electronic noise environment to read out detector signals and operational controls (e.g. shielded dewar, filtered electrical feed throughs), and
- Fast and easy cooling of the experimental setup down to the required OT.

Based on these requirements, we chose a design consisting of two separate cryogenic-cooling components: a super-insulated helium-4 dewar and a helium-3 cryocooler unit.

Custom-built by Precision Cryogenic Systems Inc., the 30-liter, helium-4 dewar is made of aluminum/fiberglass/stainless-steel and does not use liquid nitrogen as the thermal shield (i.e. no vibrations due to the continuous boiling off of nitrogen). Thanks to a sophisticated baffling system and multi-layered super-insulation, the company guarantees a hold time of 72 hours for liquid helium-4. Two hermetic multi-pin connectors are placed in its top flange to feed through the detector signal, supply and control lines. Since the dewar is mounted to a cradle, the whole assembly can be freely tilted around its axis.

Custom-built by Chase Research Cryogenics LTD., the 10-liter capacity helium-3 (model He-7) cryocooler is a multi-stage, “plug and play” refrigerator, which will be mounted onto the 4.2 K cold plate of the Helium-4 dewar. Since the cryocooler has its own small internal helium-4 bath, the vast amount of helium-4 in the dewar does not need to be pumped to reach a low enough temperature to liquefy the helium-3 in the cryocooler. Both the internal helium bath and the Helium-3 stages of the cryocooler are pumped by sorption pumps, which do not create any vibration noise during operation. The expected temperature of the cold head is 350 mK for a 10 mwatt heat load. The company guarantees a hold time of at least 72 hours. The time needed to thermally cycle the cryocooler from 4.2 K to 350 mK is less than 2 hours.

At the University of Maryland-College Park (UMCP), our collaborator developed a cryogenic pump for testing the Radio frequency Single Electron Transistor (rf-SET) superfluid flow detection. Also, the layout was completed to fabricate the first gyroscope based on the concept shown in Figure 1

At the Goddard Space Flight Center, we have identified all the required electronics to read out the SET and infer-gyroscope rotation. In summary we await the cryogenic system.

Planned Future Work:

We anticipate that our cryogenic equipment will arrive soon. When it arrives, we can start the integration of this hardware. It will take 1-2 months after delivery before we will be ready to test our first-generation gyroscope using the superfluid pump made by our UMCP collaborator. Once we complete the first test of superfluid flow measurement, we will close the fluid circuit and try to measure gyroscope rotation by orienting the device relative to the Earth’s rotational axis.

Summary:

The superfluid gyroscope we have proposed will use simple fluid dynamics and state-of-the-art Single Electron Transistor (SET) to measure rotation with a sensitivity that ultimately approaches a microarcsecond/sec/Hz$^{1/2}$, which means we would be sensitive to a rotation rate of about a microarcsecond per second. For Goddard, such a gyroscope could play a key role in pointing the next generation of high-angular resolution telescopes. For this effort, we will consider ourselves successful if we prove sensitivity to rotation and fluid flow. Detection of the Earth’s rotation will be a major milestone. The ultimate stability of this gyroscope will lie in the stability of the SET—that is our chief technical risk. It will be the goal of future efforts to calibrate dynamically SET sensitivity.